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Artificial Intelligence and Sensor Fusion

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Abstract - *Future US Air Force sensor systems must be able to adapt to changing environments in real time. A capabilities-based modeling approach is a new method being promoted for the building of the next generation weapon systems. To accommodate this modeling approach the Department of Defense (DoD) is promoting the use of waveform diversity for radar systems. Building a weapon system including one or more radar systems with waveform diversity will require the use of artificial intelligence (AI) tools and techniques. This paper investigates leveraging the AI tools being developed by the Semantic Web, DARPA's DAML program and, specifically, the building of ontologies and resource description framework (RDF) for sensor systems so that they can efficiently communicate and share their data.*

1. Introduction

The Quadrennial Defense Review 9/30/01 states: "The new defense strategy is built around the concept of shifting to a 'capabilities-based' approach to defense...A capabilities-based model - one that focuses more on how an adversary might fight than who the adversary might be and where a war might occur - broadens the strategic perspective." The DoD has always had a capabilities-based philosophy in developing weapon systems. They assessed their capabilities, projected what an enemy's capabilities would be and developed new or improved weapon systems that would provide the superiority to defeat the capabilities of adversaries. The DoD knows that the enemy is difficult to define.

"...the subject matter for most military analysts is far more fluid than during the cold war, rendering standard databases and analytical models for explaining behavior obsolete. Indications and Warning, the analysis which warns of impeding attack on the United States or its vital interests, depends on the ability to predict enemy activity, based on enemy plans, doctrine, and observed exercises and training. Many of today's potential adversaries offer little in the way of traditionally observable activity.[1]"

KIMAS 2003, October 1-3, 2003, Boston, MA, USA.

The enemy is not a single nation with borders that fights like any of our past adversaries. To win battles, the military must be able to confront adversaries in many locations with battle lines that are difficult to define, either on the earth or in cyberspace. They must be adaptable, quick, innovative, and intelligent in the use of all weapons and information. We measure the time to assess the enemy and plan for the next battle in hours and days, not years. The military can change both the features of some weapons systems and how they deploy them to meet today's military demands, e.g. unmanned air vehicles. However, other systems will take longer to modify, such as our radar and communications systems. Future US Air Force sensor systems must be able to adapt to changing environments in real time to defeat a highly unpredictable enemy.

This paper addresses an approach for building next-generation sensor systems. Section 2 provides a background on intelligent software development for radar systems. Section 3 describes an intelligent sensor system architecture. Section 4 provides an overview of ontologies and provides an abstract model of an ontology for an intelligent sensor system. The last section provides a summary and future work.

2. Background

Current signal processing systems are built assuming Gaussian clutter and are optimized for processing requirements whether the systems are mounted on an aircraft, a missile, a spacecraft, or at a ground-based site. The algorithms are "hardwired" into the computer's architecture in order to meet the real-time requirements demanded by the sensor's operating parameters, e.g. scans per second and number of sensor elements. This approach to building radar systems is currently under review by the radar research and development community because of its rigidity and high cost. This approach will evolve into more flexible and less costly

alternatives. This evolution will manifest itself in different algorithms and/or parameters that can be modified by a radar's software as its environment changes. For instance, if a radar is being jammed by a transmitter from a particular direction, then that radar could place a null in its antenna pattern in the direction of the jammer to reduce its negative affect. This, and other sophisticated algorithms have been proposed, studied and documented in published research papers.

Some of the most progressive work in employing artificial intelligence (AI) techniques has been pursued by the US Air Force Research Laboratory's Sensors Directorate. Some of their original efforts have been in the constant false alarm rate (CFAR) portion of a radar's signal processing chain. Work has been performed [2, 3] to demonstrate that if a cell under test is near the boundary of two different clutter regions, then blindly applying a CFAR algorithm (like cell averaging) will not perform as well as choosing only those cells with the same type of clutter as the test cell, and then using cell averaging. This approach provides a better probability of detection and lower false alarm rates. However, to apply this approach for a radar looking for targets whose background is the earth, requires that the registration of each cell on the earth be known and the type of clutter be categorized to determine which cells are of the same type. If the radar is resident on a moving platform looking at the earth then the algorithm must be dynamic in order to register the radar's beam on the earth for each coherent processing interval (CPI). Laboratory experiments with radar data have shown good results in using these algorithms, especially when a radar is illuminating heterogeneous clutter, such as a land-sea interface.

This work was extended beyond the detection stage to the rest of a radar's processing chain under a US Air Force (USAF) effort dealing with knowledge based space time adaptive processing (KBSTAP) [4, 5]. This effort demonstrated the benefits of using outside data sources to affect the filtering, detection, and tracking stages of a surveillance radar. Data from a side looking airborne radar system was used in demonstrating the performance enhancements over a conventional radar. The measurements were obtained from the multi-channel airborne radar measurement (MCARM) program [6] conducted by the USAF. Another program showed the benefits of using map data obtained from the US Geological Survey (USGS) to improve the performance of space-time adaptive processing (STAP) on an airborne radar by selecting range rings based on computed criteria rather than blindly choosing the range rings surrounding the test range ring. This effort, KBMapSTAP [7, 8], along with other researchers have laid the ground work for a new DARPA program. The Knowledge-Aided Sensor Signal Processing Expert Reasoning (KASSPER) program is to investigate the use of outside data sources to dynamically change a radar's signal processing chain to enhance a radar's performance.

Can we build new radar systems that can dynamically change its processing given information from other sensors, outside sources, weather data, etc.? We believe that we can. The computing clock rates for computers have been doubling approximately every 18 months. Today's commercial off the shelf computers have clock rates exceeding 3 GHz. We believe that the computing power is available to insert sophisticated "rules/logic" within radar signal and data processing.

We need a new approach for building the next generation systems, not only for single radar systems, but also for a platform of sensors. Sensors should be modeled not as stove pipe systems, but as a system of sensors, whether mounted on a single platform or on multiple platforms. Waveform diversity is defined as that technology that will allow one or more sensors onboard a platform to automatically change operating parameters, e.g. frequency, gain pattern, pulse repetition frequency (PRF), etc. The system of sensors can then fuse information and allow a sensor to change its operation to meet the varying environments that military systems face and to meet the intent of a capabilities-based approach. The reader is referred to a companion paper in these proceedings [9] which provides more explanation of waveform diversity.

3. An Intelligent Sensor System

If an airborne radar is going to share and receive information from multiple sources then it must be able to communicate and to understand this information. A solution for exchanging information between heterogeneous sensors is for each sensor to publish information based upon an agreed upon and understood format (i.e. an ontology). Therefore, when a sensor publishes its track data, multiple sensors that receive this information will be able to interpret the contents without ambiguity. Sharing data among sensors will require that certain basics be established. There must be an accepted method of defining the earth's geometry such that the positions of every element on the earth, in the air or in space use the same coordinate system. Each element must be synchronized from the same clock and all communications must be time stamped.

Each transmission of information between sensors must include time and spacial coordinates. In addition, if the sensor is sharing track or target data, it must specify a unique identifier, and the sensor platform's velocity, pitch, yaw, and role, and include metadata describing the transmitted raw data along with encryption/decryption keys. A unique identifier allows the receiving sensor to store all of the sender's radar characteristics within its resident database management system (DBMS). Sensor

characteristics include such things as nomenclature, power output, bandwidth, frequency, antenna pattern, pulse width, pulse repetition frequency (PRF), etc. Platform characteristics include the position of the antenna on the platform, number of elements, the pattern of the elements, the pointing vector of the radar, etc. This process requires a standard method for defining these data and numerous rules so that the information published by any sensor can be understood correctly by the receiving sensor. The receiving sensor can then perform functions such as sensor fusion, track correlation, and target identification. This standard definition should be in an ontology.

Advances in radar technology also require sharing information between sensors on the same platform, especially if one or more sensors are adaptively changing its waveform parameters to meet the demands of a changing environment. Figure 1 depicts a hypothesized intelligent sensor system. Each of the sensors has its own signal and data processing functional capability. In addition to this capability, we have added an intelligent processor to address fusion between sensors, communication between sensors, and control of the sensors. The goal is to be able to build this processor so that it can interface with any sensor and communicate with the other sensors using ontological descriptions via the intelligent platform network. The intelligent network will be able to coordinate the communications between the sensors onboard and to off platform sensor systems. There are approaches we can exploit to build this system by using fiber optic or wire links onboard the platform. Radio frequency (RF) links using Bluetooth or 802.11 technologies can be exploited for linking these sensors onboard the platform. Between platforms other technologies may be exploited such as mobile internet protocol over RF communications links. The communications issues need to be addressed for the sharing of information and for minimizing the potential of electromagnetic (EM) fratricide. The intelligent platform should determine if there is EM interference (EMI) potential when a sensor varies their antenna's main beam pointing vector, or changes its PRF and may thereby cause interference to a receiving sensor. Rather than have each sensor on a platform operate as an independent system, we need to design a platform as a system of sensors with multiple goals managed by an intelligent platform network that can manage the dynamics of each sensor to meet the common goal(s) of the platform. This is one of the major issues we are pursuing under the Sensors as Robots Initiative. This initiative addresses both attended and un-attended sensor platforms.

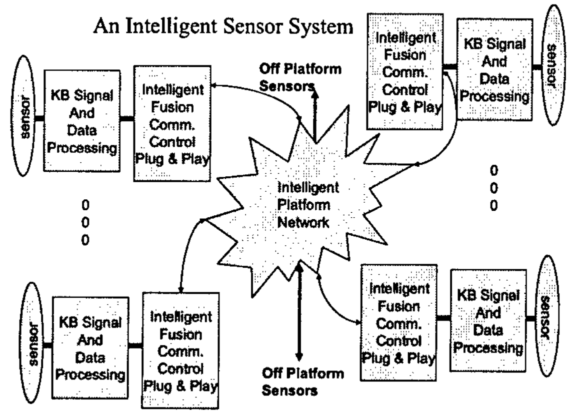

Figure 1 - An Intelligent Sensor System

4. Ontologies

One key in building an intelligent sensor system is leveraging the efforts of the artificial intelligence (AI), the Internet, and the software communities. The Internet community is building technologies that allow software agents not only to read, but to understand documents and resources available on the World Wide Web. Its goal is to enhance the exchange of information and to provide the tools for the Web to become more business friendly and more profitable. However, the results of these efforts can also be used to build intelligent sensor systems where multiple sensors can communicate and understand each other automatically with only minimum human intervention.

The Internet community is represented by an organization whose definition is found at www.w3c.org: "The World Wide Web Consortium (W3C) develops interoperable technologies (specifications, guidelines, software, and tools) to lead the Web to its full potential. W3C is a forum for information, commerce, communication, and collective understanding." They, along with the Defense Advanced Research Project Agency's (DARPA) Agent Markup Language (DAML) program, are building the next generation Internet, the Semantic Web. The goal of the Semantic Web is to provide mechanisms for Web publications that can be read and understood by software. Currently, most Internet content requires a human to understand its meaning, and is designed to push text and images to readers, not software. Search engines usually provide such a wide array of varied results that they must be filtered by a human. For example, a search for "radar signal processing" returns a list of almost any site with any of those words, whether or not they are actually in the radar domain. The Semantic Web is being designed in a manner similar to a large knowledge base such that a domain is defined specifically in an ontology, or series of ontologies that standardize the terms, relationships and meanings within the domain, such as radar or sensors in general. A radar or signal processing ontology may be

defined in the same manner as other Internet ontologies. Dr. Tom Gruber defines an ontology at http://www-ksl.stanford.edu/kst/what-is-an-ontology.html:

"An ontology is a specification of a conceptualization....What is important is what an ontology is *for*. ... For pragmatic reasons, we choose to write an ontology as a set of definitions of formal vocabulary. Although this isn't the only way to specify a conceptualization, it has some nice properties for knowledge sharing among AI software (e.g., semantics independent of reader and context). Practically, an ontological commitment is an agreement to use a vocabulary (i.e., ask queries and make assertions) in a way that is consistent (but not complete) with respect to the theory specified by an ontology. We build agents that commit to ontologies. We design ontologies so we can share knowledge with and among these agents."

The concept of an ontology is exactly what is needed in the overall pursuit of the goal to have sensors operate in cooperation and eventually have sensor platforms operating autonomously as robots. For sensors to operate cooperatively they must be able to communicate, to share data and information, and to understand each other and their environments. If each sensor system builds its own knowledge base with different knowledge base representations it would be almost impossible for them to communicate and understand each other beyond only the simplest configurations. Each system would have to build software translators to understand every other. Each sensor system would have N-1 translators for a system with N sensors. This would be expensive to build, processor intensive, and would generate a high maintenance cost over the life of the sensor systems. Adding new systems would require updates to all the other systems.

Leveraging the approach and technology of the W3C, the radar community can develop ontologies for sensors, creating a single knowledge base structure that can be understood by all new knowledge base sensor systems added to the overall domain, including communications, radar, electro-optical, infrared, acoustic, etc. This approach will allow multiple sensors on one platform to inference and fuse data and information from all its sensors onboard. It will also allow this platform to share and fuse data and information between sensors on multiple platforms located nearby or miles away within a command center. Ontologies are currently being defined, built and applied to many varied domains, commercial and academic. They are easily found on the Web and can be used to build and share information within the community and domain of interest. The approach we recommend and used [10] is not to build one's own ontology from scratch, but to utilize inheritance (similar in concept to object-oriented inheritance) and reference other ontologies for more fundamental entities. The ontology will be created as a resource description framework (RDF) (i.e. an instantiation of an ontology) referencing those existing ontologies, and add those additional facts and rules required for the domain. For example, if an organization wants to build RDFs describing facts and rules for a transmitter, a receiver, and an antenna, the organization should determine if other ontologies exist which define those facts and rules, then those ontologies should be referenced within this RDF, rather than building a whole new ontology. In this manner one needs only to refer to the ontology containing rules and facts they wish to use and add additional rules and facts as required.

To illustrate building a sensor ontology consider figure 2. This is a partial model and is just the beginning of defining the classes and properties that will be needed. Not included in figure 2. are numerous other ontologies containing definitions, rules and properties we wish to use. Some of these ontologies are (in XML syntax):

<!ENTITY rdf 'http://www.w3.org/1999/02/22-rdf-syntax-ns#'>
<!ENTITY rdfs 'http://www.w3.org/2000/01/rdf-schema#'>
<!ENTITY daml 'http://www.daml.org/2001/03/daml+oil#'>
<!ENTITY xsd 'http://www.w3.org/2000/10/XMLSchema#'>
<!ENTITY dc 'http://dublincore.org/2002/08/13/dces#'>
<!ENTITY dcterms 'http://dublincore.org/2002/08/13/dcq#'>
<!ENTITY prf 'http://www.wapforum.org/profiles/UAPROF/ccppschema-20020710#'>
<!ENTITY cti 'http://www.caprarotechnologies.com/IMP/device/daml+oilbased-ccppschema-20021018#'>.

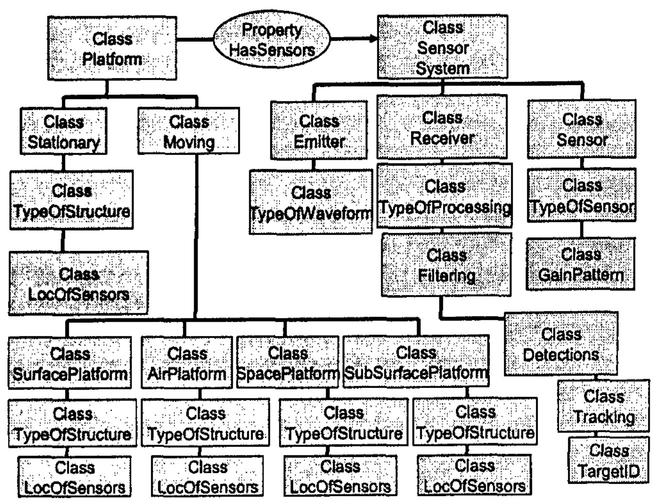

Figure 2 - A Partial Model Sensor Ontology

In figure 2 we have defined only two major classes i.e. the sensor system class and platform class. A platform has the property that it has one or more sensors onboard. A platform may be fixed, such as a ground radar site or command and control center. If the platform is moving, then it may be on the surface of the earth, in the air, in space or beneath the earth's surface, e.g. a submarine. A typical air platform might be a helicopter, a fighter aircraft, or surveillance aircraft. On any of these platforms the geometry for describing where a sensor is located is required. Because these types of platforms are so different, we separated them into different classes. We have defined a sensor system as being composed of an emitter, receiver and sensor class. In the diagram for a sensor class, we refer to the device that is emitting or receiving the wavelength of choice. For instance, if the sensor system is a radar system, then the sensor class would be the radar's antenna. If the sensor system is an optical system, then the sensor class would be its lens.

The important point of this ontology, is that for any system we want to describe, we can create an RDF that describes that system in standard terms. Spelling, meaning, inference rules and syntax are precisely defined so that any ontology-aware software built to integrate systems can accept new systems without reprogramming. In figure 2, the tag "TypeOfStructure" is a case sensitive, fully-defined entity with a precise syntax, datatype, range of acceptable values and meaning. Given that, software can look at the RDF, determine the type of structure, and start accepting data from this structure.

5. Summary and Future Work

A motivation for a new approach for building our next generation sensor systems was presented. A background section provided an overview of some of the military funded work that is integrating artificial intelligence technology into our sensor systems was presented. An intelligent sensor system was described along with a description of ontologies. We also provided a partial model of a sensor ontology which provides the basis for multiple sensors to share information for sensor fusion and waveform diversity. Future work needs to be performed in the design of the intelligent sensor system and in the definition and development of a sensor ontology as a basis for building a system of sensors both onboard a platform and between multiple platforms.

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